High-density V-groove InGaAs/AlGaAs quantum wires on submicron gratings by constant growth technique

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Abstract

High-density InGaAs/AlGaAs quantum wire (QWR) structures with a period of 430 nm were successfully grown by using constant metalorganic chemical vapor deposition growth technique in which submicron gratings were preserved even after an epitaxial growth of 1 \textmu m thickness. The quantum confinement effect of the InGaAs/AlGaAs QWRs is strong due to the large band offset and enhanced migration of surface adsorbed III-group element species compared with the GaAs/AlGaAs QWRs. The photoluminescence signal of the InGaAs/AlGaAs QWRs was observed in the temperature range from 10 to 300 K with a relatively narrow full width at half maximum of <40 meV. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

Semiconductor nano-structures such as quantum wires (QWRs) have attracted much attention due to their potential applications in photonic devices such as laser diodes and photonic switches. Selective metalorganic chemical vapor depositions (MOCVD) on nonplanar substrates have been widely paid attention because high quality QWRs are realized without lithographic resolution. For the first time, we have fabricated high-quality QWR structures by flow-rate modulation epitaxy [1] and realized the ground state lasing operation in V-groove QWR laser [2]. However, the active region volume of the QWRs tends to be too small compared with that of the QWs, and it deteriorates the efficiency of the optical devices. In order to overcome this problem, high-density QWR array structures should be desirable. Recently, we developed the constant MOCVD growth technique in which submicron gratings were preserved even after the growth of 1 \textmu m thickness. We
fabricated high-density V-groove GaAs/AlGaAs QWR structures on submicron grating using the constant MOCVD growth technique [3]. By this technique, complex photonic devices such as gain-coupled distributed feedback (DFB) lasers have also been fabricated [4]. The potential advantage of the constant growth technique is the fact that such a complex structure can be grown by one-step growth without interface defects due to the elimination of ex–situ etching and regrowth of buried heterostructures.

Strained InGaAs structures are very important for the practical applications since the emission wavelength range will extend toward the optical telecommunication windows [5]. It also favors high-temperature excitons because of strong confinement between InGaAs and AlGaAs. In this study, high-density InGaAs/AlGaAs QWR structures are realized by the constant MOCVD growth technique on submicron grating.

2. Experimental procedure

The submicron gratings with a period of 430 nm and a grating depth of 200 nm were fabricated by a conventional holography and a wet chemical etching method along the [0 1 1] direction on (1 0 0) n+ -GaAs substrates. Epitaxial growth was carried out in a horizontal quartz reactor with a face-down configuration by a low-pressure MOCVD technique at 76 Torr. The V/III ratio was 200. Triethylgallium, trimethylaluminum, trimethylindium, and AsH₃ were utilized as source reagents. On the GaAs submicron gratings, an Al₀.₃₈Ga₀.₆₂As epilayer of about 900 nm thickness was grown as a lower cladding layer of the DFB lasers. As the core layer with a thickness of 140 nm, Al₀.₂Ga₀.₈As and In₀.₂Ga₀.₈As were grown between the upper and lower cladding layers. The content of indium was measured by energy-dispersive spectroscopy. For the growth with conservation of grating structure up to 1 µm height, optimization of the growth temperature, GaAs buffer, and grating shape are very important as discussed elsewhere [3]. An optimum growth temperature was 680°C for the constant growth method. In order to investigate the structural and optical properties of the InGaAs QWRs, we have also grown In₀.₂Ga₀.₈As/Al₀.₃₈Ga₀.₆₂As and GaAs/Al₀.₃₈Ga₀.₆₂As QWR structures without thick cladding layer by constant MOCVD growth technique.

The cross sections of the samples were observed with a high resolution scanning electron microscopy (SEM) and transmission electron microscopy (TEM). All samples were characterized by PL measurements over a temperature range of 10–300 K using λ = 514.5 nm line of a cw-Ar⁺ laser as the excitation light. The Ar⁺ laser was focused on the sample surface to a spot diameter of about 100 µm and power of the laser beam was about 15 mW.

3. Results and discussion

The cross-sectional SEM image of a gain-coupled InGaAs/Al₀.₂Ga₀.₈As QWR DFB laser structures by one-step constant MOCVD growth technique is shown in Fig. 1. InGaAs/Al₀.₂Ga₀.₈As QWRs are well formed on 1-µm-thick Al₀.₃₈-Ga₀.₆₂As cladding region without regrowth process which causes the interface defects.

Fig. 2 shows the cross-sectional TEM image of the InGaAs/Al₀.₃₈Ga₀.₆₂As QWR structure without thick cladding layer. The InGaAs QWRs are well confined at the bottom of the grating. The vertical thickness of the QWR is about 7 nm. Parasite quantum wells (QWs) are also observed at the side-wall and top of the grating just as in the case of GaAs QWR structures [1]. Since the grating pitch is small and the top-shape of the grating is sharp, the area of top QWs is small compared with that of the side-wall QWs. Although the side-wall QWs still exist, its thickness is very thin compared with that of QWRs at the bottom of the gratings because an indium migration rate is fast due to the larger diffusion coefficient [6]. Therefore, the difference in energy of the quantum ground states between the QWRs and the parasite QWs is expected to be large because the size of these two structures is not the same as shown in Fig. 2.

Fig. 3(a) shows the PL spectra at 10 and 200 K of GaAs/Al₀.₃₈-Ga₀.₆₂As QWRs structure fabricated
by the constant MOCVD growth as mentioned above. At 10 K, we can observe the PL peaks from the GaAs QWRs and the parasite QWs at 1.61 and 1.66 eV, respectively. The energy difference is 50 meV. The PL peak at 1.51 eV originates from impurities. The PL peak intensity of the GaAs QWRs is smaller than that of the QWs just as in our previous result [1]. As the temperature increases, the energy of both the peaks shifts to low-energy side due to change of the band gap energy, and the relative peak intensity of QWRs is getting larger compared with that of QWs as shown in PL spectrum at 200 K. The PL peaks of GaAs QWRs and QWs are not observed when the measurement temperature is above 200 K. Fig. 3(b) shows the PL spectra at 10 and 300 K of the InGaAs/AlGaAs QWR structure. At 10 K, four PL peaks located at 1.42, 1.49, 1.51 and 1.63 eV are clearly observed, which are attributed to the PL from GaAs QWRs, GaAs substrates, impurities, and parasite InGaAs QWs, respectively. The PL peaks of the InGaAs QWRs and the QWs are well separated.
compared with the case of the GaAs QWRs structure. The PL peak energy of InGaAs QWRs is lower than QWs by 210 meV, since the QWRs are thicker than the QWs due to the fast indium migration towards the bottom of the grating. Carriers in this structure tend to accumulate in the QWRs region. Furthermore, in the case of InGaAs/AlGaAs QWRs, the band offset between QWRs material and barrier material is larger than the case of GaAs/AlGaAs. Therefore, the quantum confinement effect of the InGaAs/AlGaAs QWRs is quite strong.

Fig. 4(a) shows the temperature dependence of the integrated PL intensity of GaAs/AlGaAs QWRs and QWs. The solid square and open circles represent the integrated intensity of QWRs and QWs, respectively. As the temperature increases, the PL intensity of parasite QWs rapidly decreases, while the intensity of GaAs QWRs slightly increases until 90 K and rapidly decreases above 100 K. Since the difference in the energy of the both peaks and the integrated intensity of the GaAs QWRs are not sufficiently large, it is difficult to analyze both the PL peaks separately. For the fine analysis of the PL peaks, it is necessary that the parasite side-wall and top QWs should be removed by etching just as in the case of a PL study of QWRs grown on gratings with a period of several microns [7]. Fig. 4(b) shows the temperature dependence of the integrated PL intensity of InGaAs/AlGaAs QWRs and QWs. As the temperature increases, the PL intensity of parasite InGaAs QWs rapidly decreases and is not observable at room temperature as in the case of GaAs structures. In contrast to the GaAs structures, the PL intensity of InGaAs QWRs is not significantly changed from 70 to 220 K due to the carriers in the QWs transfer to the more stable state in the QWRs by thermal activation. As a consequence, the strong PL intensity from InGaAs QWRs can be observed up to room temperature with a relatively small full width at half maximum of less than 40 meV as shown in Fig. 3(b).

4. Conclusion

In conclusion, high-density InGaAs/AlGaAs QWR structures with a period of 430 nm have been successfully grown by using constant MOCVD growth technique in which submicron gratings were preserved even after the epitaxial growth of 1 μm thickness. The potential advantage of this technique is the fact that the complex optical devices such as gain-coupled DFB laser can be fabricated on the submicron grating by one-step MOCVD growth. Large band offset between InGaAs and AlGaAs and fast indium migration lead to the strong quantum confinement effect of the InGaAs/AlGaAs QWRs compared with the GaAs/AlGaAs QWRs. The PL signal of the InGaAs/AlGaAs QWRs was observed in the temperature range from 10 to 300 K with a relatively narrow full-width at half-maximum of less than 40 meV.
References